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ANALYSIS OF ANELASTIC DEFORMATION RESPONSE IN Fe-B  
AMORPHOUS SYSTEM<sup>1</sup>

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Anelastic creep aftereffect curves measured on Fe<sub>100-x</sub>B<sub>x</sub> ( $x = 14, 17, 20$ ) amorphous alloys under isothermal conditions in the temperature range of 458–637 K have been analysed by two independent direct spectrum analysis methods. Obtained spectra consist of three or more characteristic peaks, each of them represents a type of elementary deformation process. The influence of the structural relaxation, the boron content and the temperature on the shape of the spectra is demonstrated and discussed.

## 1. Introduction

Physical and mechanical properties of amorphous metallic materials – metallic glasses are substantially determined by characteristics of their structural "defects". From the mechanical properties point of view these defects can be characterized as soft regions in amorphous structure which can be deformed much more easily than their surroundings. Different definitions of such defects in amorphous structure have been proposed up to now: (i) free volume concept [1]; (ii) stress inhomogeneities at atomic level [2]; (iii) noncoincident atomic sites configuration at intercluster boundaries [3].

Creep recovery can be considered as the most "pure" anelastic deformation experiment because it takes place without any (or with very low) external stresses. Results and analysis of such experiments seem to be important in crucial appreciation of the models above. It was the reason why we decided to study properties of deformation defects in metallic glasses via the analysis of anelastic deformation response.

## 2. Experimental and Calculations

Amorphous ribbons of Fe<sub>100-x</sub>B<sub>x</sub> ( $x=14, 17$  and  $20$ ) were prepared at the Institute of Physics SAS in Bratislava by the rapid quenching process. Samples for creep recovery tests were ground from as received ribbon to the shape usually used for tensile testing with the width of 0.35–0.65 mm and effective length of 12 mm. Measurements were

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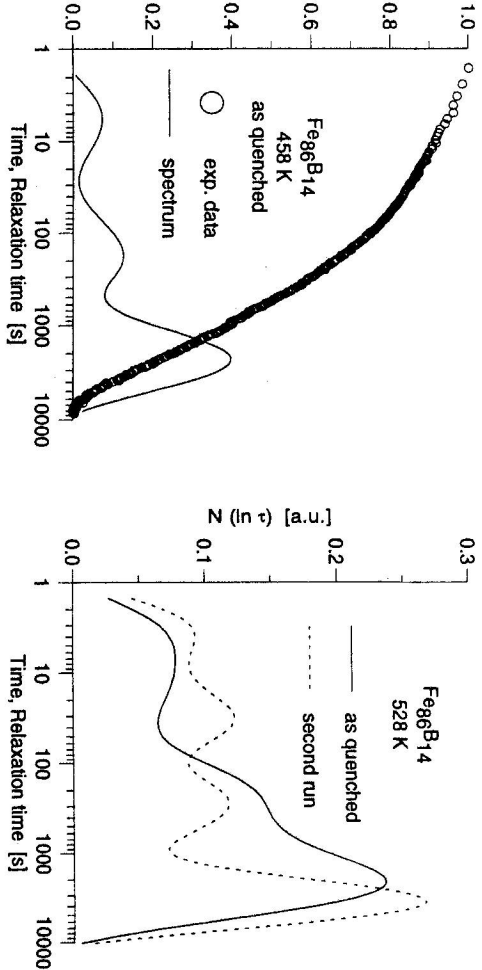


Fig. 1: Normalized creep recovery curve  $f(t)$  for  $\text{Fe}_{66}\text{B}_{14}$  amorphous alloy measured at 458 K in as-quenched state (points) and calculated relaxation time spectrum (solid line).

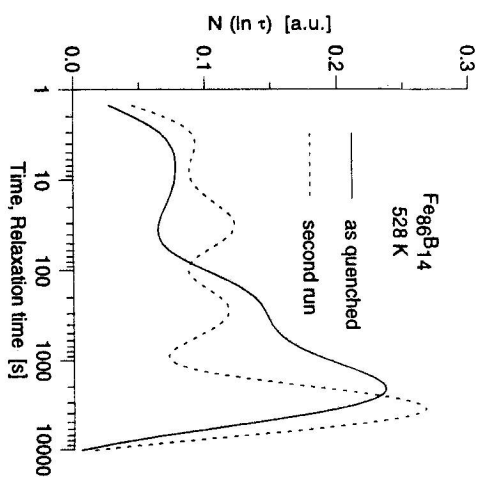


Fig. 2: Creep recovery spectra for  $\text{Fe}_{66}\text{B}_{14}$  amorphous alloy measured at 528 K in as-quenched state (solid line) and in second run (dashed line).

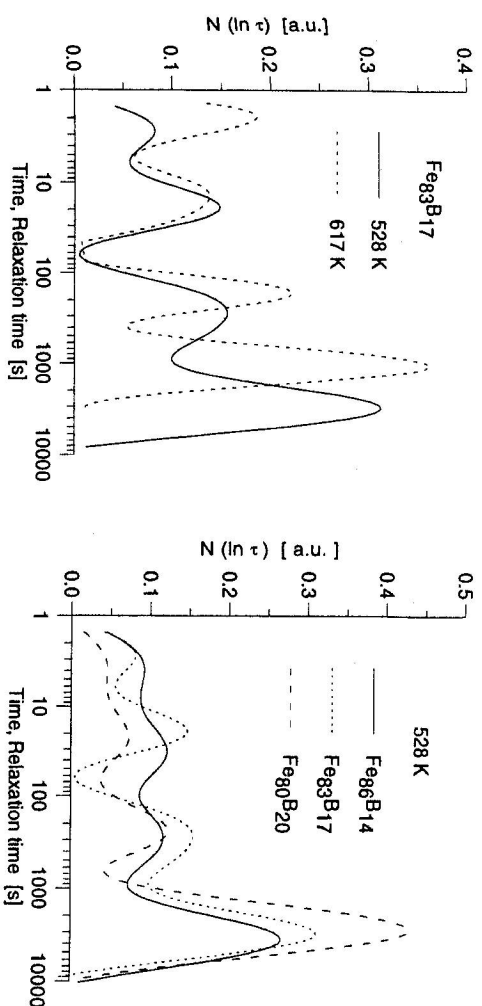


Fig. 3: Creep recovery spectra for  $\text{Fe}_{63}\text{B}_{17}$  amorphous alloy measured at 528 K (solid line) and at 617 K (dashed line).

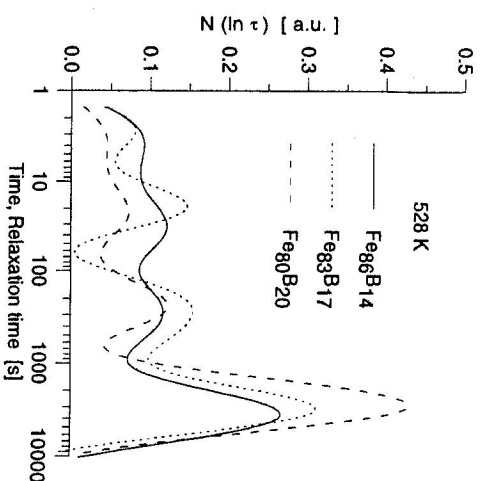


Fig. 4: Creep recovery spectra for  $\text{Fe}_{100-x}\text{B}_x$  amorphous alloy measured at 528 K.

### 3. Results

carried out in a SETARAM TMA 92 thermomechanical analyzer which has a displacement resolution of 10 nm. The prepared samples were heated to the test temperature (558, 528, 617 and 637 K) with the heating rate of 10 K/min and under tensile stress about 100 MPa. The stress was kept until steady state creep was reached and on moving it creep recovery  $f(t)$  was measured. To compare results in as-quenched and fully relaxed samples the same measurement has been repeated on the same sample the second run.

Relaxation behaviour in amorphous metallic systems is rather spectrum of simpler kinetics than a single one, thus in isothermal experiment  $f(t)$  can be represented in an integral form:

$$f(t) = f_0 \int_{-\infty}^{+\infty} N(\ln \tau) \exp(-t/\tau) d \ln \tau, \quad (1)$$

where  $N(\ln \tau)$  is the relaxation time spectrum,  $\tau$  is the relaxation time and  $f_0$  is the normalization factor. Up to now two methods for calculation of  $N(\ln \tau)$  without forcing the results to any particular shape of the distribution have been proposed [4, 5]. Both these methods have been used in our calculations and both of them gave coincident results. Arrhenius law

$$\ln \tau = \ln \tau_0 + E/kT, \quad (2)$$

where  $\tau_0$  is reverse Debye frequency,  $E$  is activation energy,  $k$  is the Boltzmann factor and  $T$  is the temperature, has been used to compare spectra calculated by these two methods. Here we present only results obtained using the method based on discrete Fourier transformation [5].

Figure 1 shows typical time dependence (in  $\ln t$  scale) of normalized creep recovery curve measured at 458 K on  $\text{Fe}_{66}\text{B}_{14}$  amorphous alloy in as-quenched state. Relaxation time spectrum computed from experimental data is also shown. Spectrum consists of finite number of peaks with well defined characteristic relaxation times of 6, 175 and 2400 seconds. Peaks in the relaxation time spectrum are nearly symmetrical on the  $\ln \tau$  scale, so they may be a good fit to a lognormal distribution in time. This character of the spectrum is in good agreement with the results obtained for  $\text{Fe}_{40}\text{Ni}_{40}\text{B}_{20}$  [6, 7, 8] and for  $\text{Fe}_{40}\text{Ni}_{40}\text{P}_{14}\text{B}_6$  [10] amorphous alloy.

The decrease of the width of relaxation time peaks during the structural relaxation has been reported for  $\text{Fe}_{40}\text{Ni}_{40}\text{B}_{20}$  [7] and for  $\text{Ni}_{77}\text{Si}_{17}\text{B}_{15}$  [9] amorphous ribbons. The same phenomenon we observed in our experiments. Figure 2 shows the comparison of two spectra obtained on the same sample in two subsequent runs. It is seen that the relaxation time spectrum in more relaxed state is changed close to the discrete type with the sharper characteristic relaxation times.

The influence of temperature on the observed relaxation time spectra is demonstrated in Fig. 3 where spectra for  $\text{Fe}_{63}\text{B}_{17}$  measured at two different temperatures are shown. Shift of the centers of peaks to the shorter relaxation times is observed for all peaks.

The change of the relaxation time spectrum with the chemical composition is shown in Fig. 4. The character of the spectrum as a superposition of four near lognormal peaks is preserved for different boron content alloys. Deformation processes with higher relaxation times ( $\approx 300$  and  $\approx 3000$  s) play more important role in alloys with higher boron concentration.

#### 4. Discussion

The fact that the creep recovery spectrum is multimodal rather than a broad single peak gives new essential information for understanding the mechanisms of atomic rearrangements during deformation and the short-range ordering process in amorphous alloys.

Rather good experimental evidences of a dislocation like mechanism of the plastic deformation of amorphous metallic materials exists in the literature [11] but there is no microscopic notion about dislocations in amorphous structure and accomplish their plastic deformation. On the other hand the polycrystal model [3] precisely indicates dislocation-like atomic defects responsible for plastic deformation. These are noncoincident atomic sites configuration at the boundaries of polycrystals.

Moreover the polycrystal model unlike others can explain why the relaxation time spectrum has rather discrete character than a broad one. Namely the number of possible types of atomic rearrangements in the intercluster boundary during some kinetic process is finite [3]. We would like to note that the spectrum of positron annihilation lifetimes in a metallic glass ribbon has also a discrete character [12].

The tendency for relaxation time spectra of thermally activated processes to fit a lognormal distribution has been discussed in detail in [13]. From the temperature dependence of peaks width  $\beta$  one can distinguish (see eq. 2) whether a thermally activated relaxation tends to be controlled either by a distribution of activation energies (with a constant pre-exponential factor) or a distribution of frequency factors (with a constant activation energy). For the later case the distribution parameter  $\beta$  is independent on temperature while for the former case the peaks must broaden with decreasing temperature. In our experiments the shift of the center of peaks to the shorter relaxation time and the reduction of the peak width with increasing temperature (so typical for the case when thermally activated relaxation tends to be controlled by a distribution of activation energies) are not observed for all peaks. It shows another evidence that each peak represents a distribution of different type of deformation defects.

There is a hierarchy of internal stresses of different ranges in amorphous metallic materials obtained by rapid quenching process. This hierarchy consists of: (i) macroscopic quenching stresses (acting on the scale of the whole sample) [14, 15], (ii) submacroscopic quenching stresses (acting on the scale of several hundredths of micrometers) [16] and (iii) local stresses of intercluster boundaries [3] or atomic level stresses [2]. The decrease of the width of peaks in the relaxation time spectra during the structural relaxation evidently attributed to the first two mentioned types of internal stresses. Different signs of these stresses in different regions of the ribbon cause a blurring of each relative sharp peak.

#### 5. Conclusion

Analysis of the anelastic creep aftereffect on  $\text{Fe}_{100-x}\text{B}_x$  ( $x = 14, 17, 20$ ) amorphous alloys using methods for relaxation time spectra calculation shows that deformation effects which take part on anelastic deformation process in amorphous structure can

be clearly classified according to the time which they need for realization of an elementary deformation process. Observed spectra consist of three or more relatively sharp characteristic peaks, each of them represents a type of elementary deformation process.

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